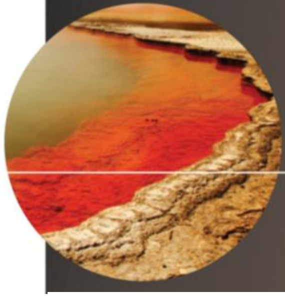


5th International Conference GEOPROC 2015 Welcome!

The Next Generation of Unconventional Resource Reservoir Simulators

GEOPROC

Multiscale and Multiphysics Simulations with full THMC coupling

Klaus Regenauer Lieb[1,2*], Rob Jeffrey[2], Sheik Rahman[3], Mike Trefry[2,1], Ali Karrech[2,1], Andrew Bunger[2], Arcady Dyskin[1], Xi Zhang[2], Bisheng Wu[2], Manolis Veveakis[2] , Christoph Schrank[4], Florian Fusseis[5] , Thomas Poulet[2], Jie Liu[1**], Vladimir Lyakhovsky[7],Oliver Gaede[6], Dave Yuen[8], Robert Podgorney[9] and Thomas Kohl[1]

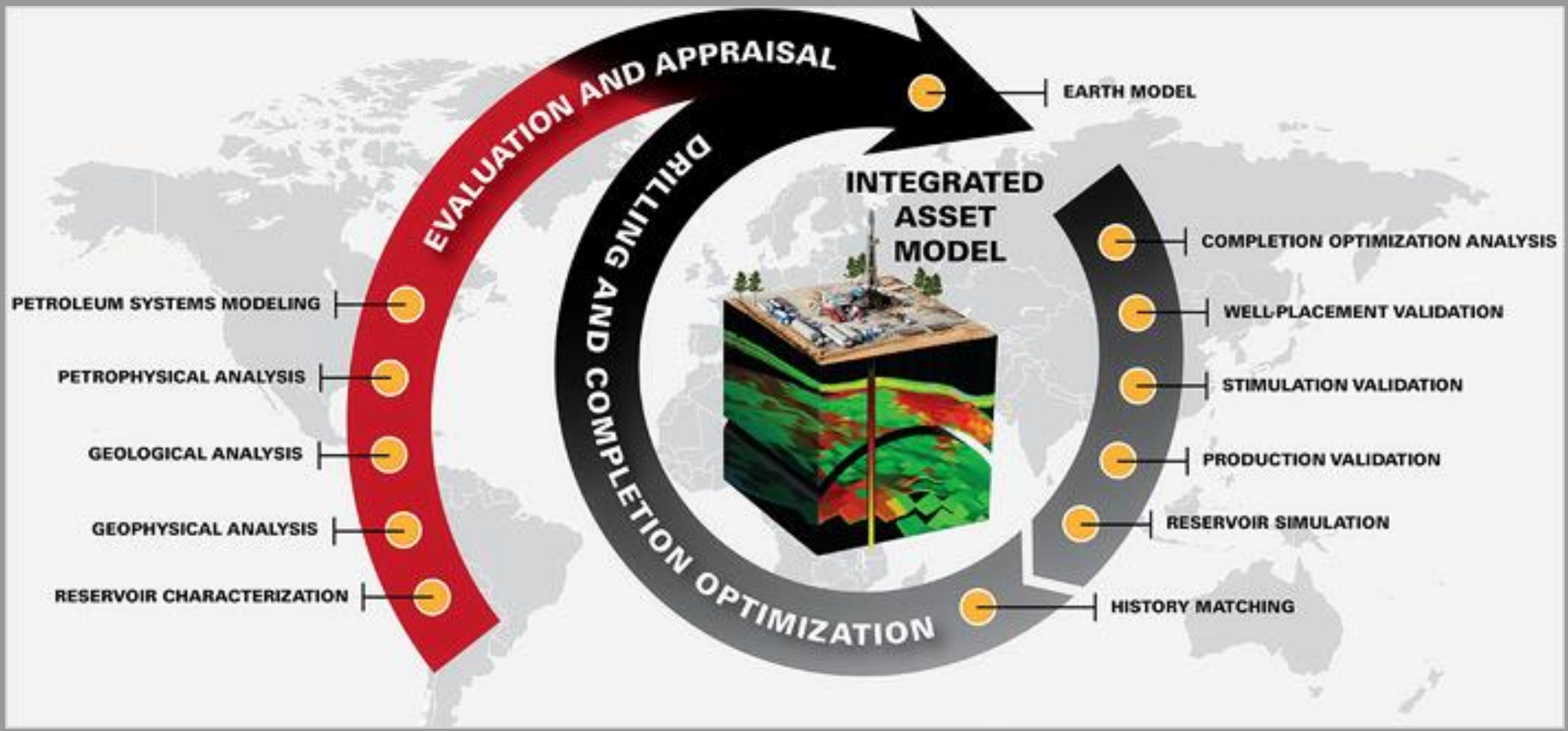
International Partnership for Geothermal Technology

Unconventional Resources, the moon landing mission in the energy and mineral space

We go deeper and hotter than ever achieved before

The Apollo space programme cost was given as **$25.4 billion**, around $150 billion (£93bn) in today's money.

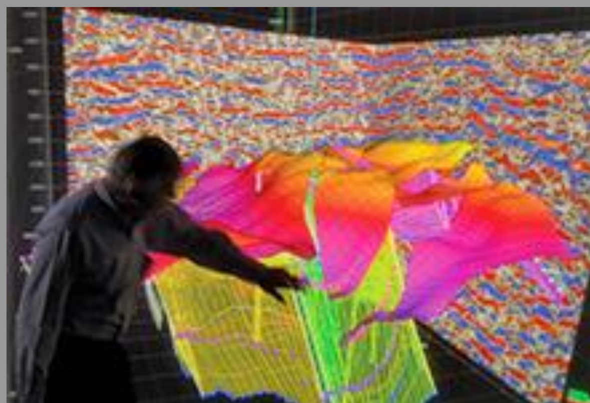
Industry Take on Unconventional Resources: Example Halliburton

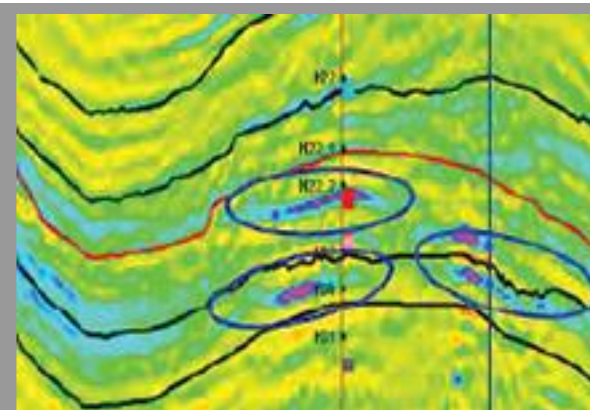


What Can Halliburton Consulting Do for You in Unconventionals?
We have the people

an integrated team of geologists, geophysicists, petrophysicists and drilling and completions personnel

Industry Take on Unconventional Resources: Example Schlumberger





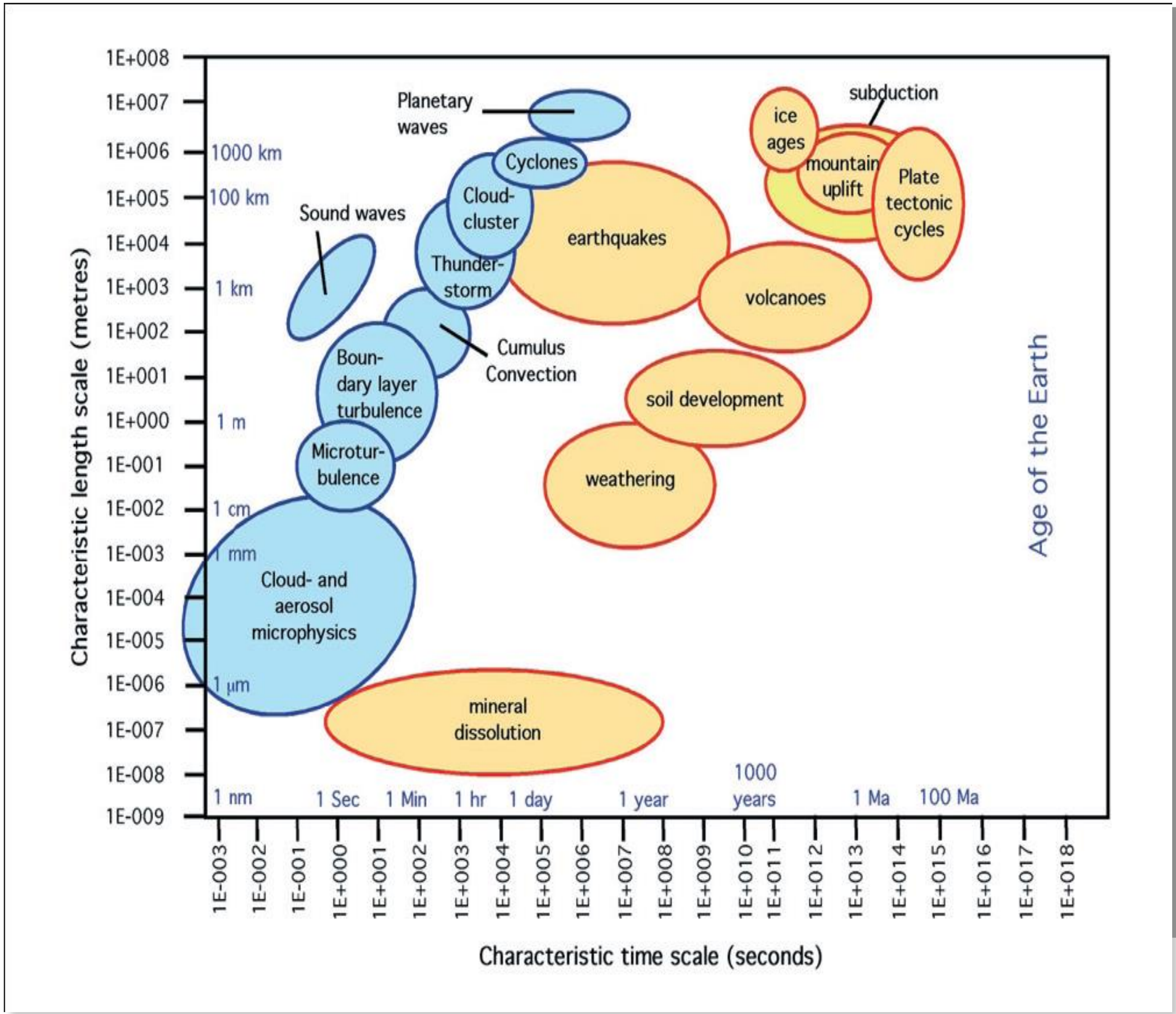
Combining geophysical and geological data interpretation with real-time services

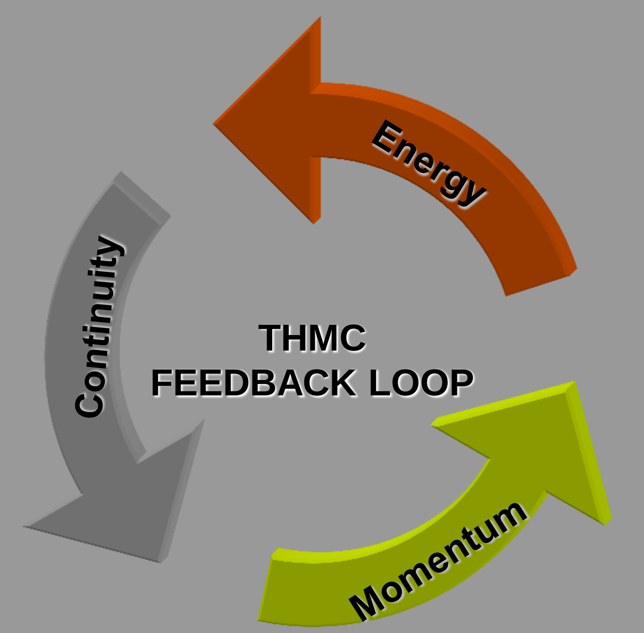
Multidisciplinary petrotechnical consultants reinterpret available data to advance gas-condensate reservoir operations

Delivering a sophisticated, multidisciplinary reservoir study

Working in collaboration with Vietgazprom, the Schlumberger PetroTechnical Services team in Moscow undertook the analysis and reinterpretation of existing 2D and 3D seismic and well data

Geoproc: a hybrid analytical-numerical-laboratory modeling of multiscale and multiphysics processes

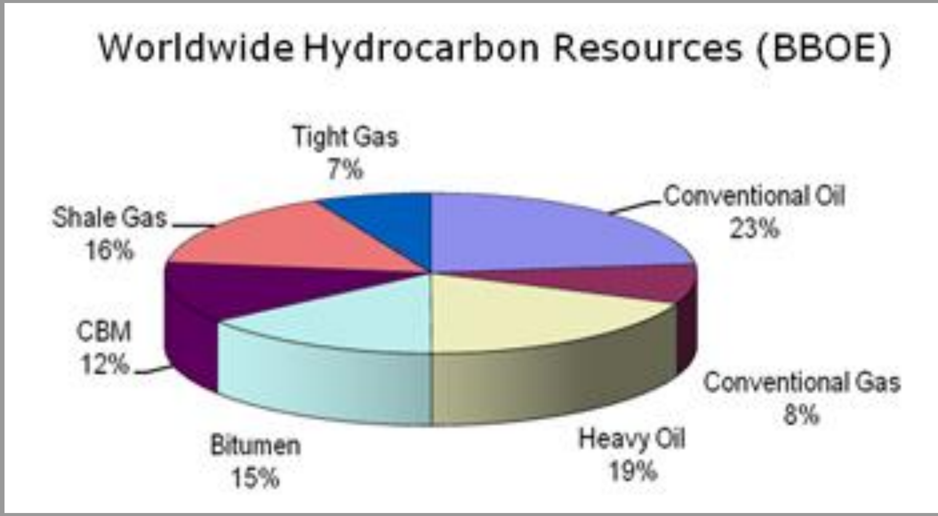




Research must think beyond consultancy

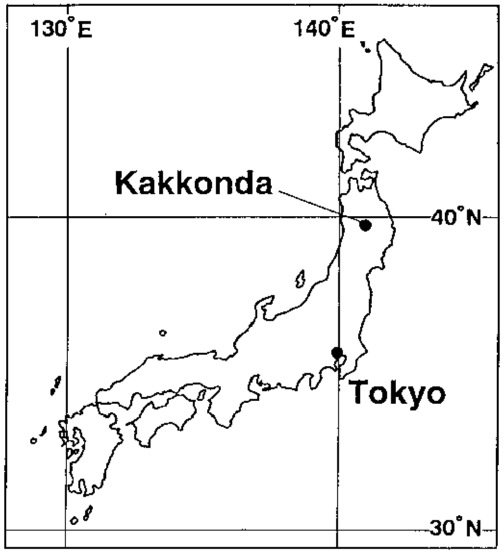
- Consultancy definition of unconventional resources are:
  - Tight Gas
  - Coalbed Methane (CBM)
  - Shale Gas
  - Shale Oil
  - Heavy Oil/Tar sands
  - Methane Hydrates

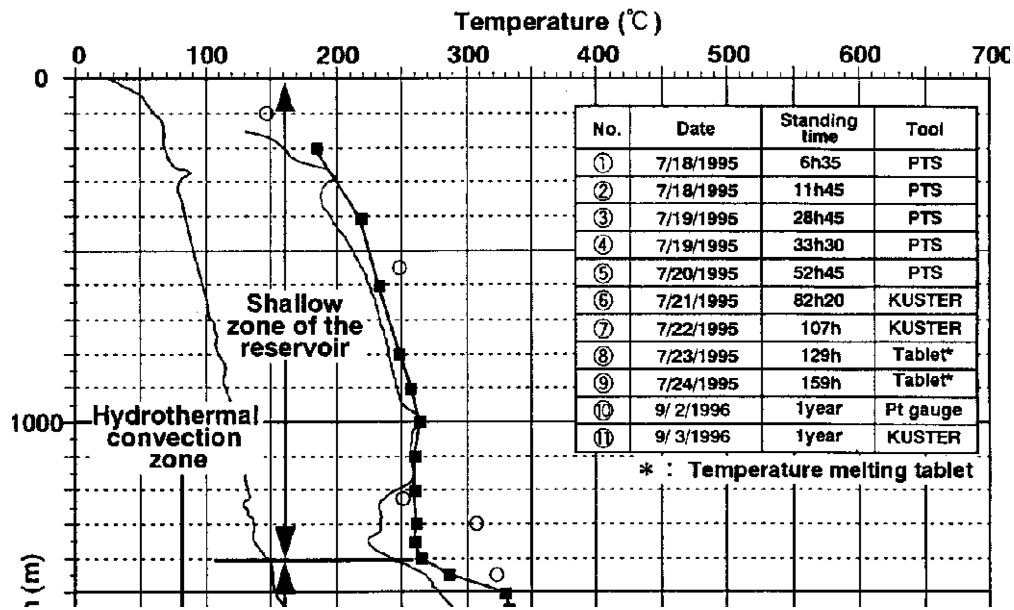
http://www.cgg.com/



The Ultimate Unconventional Resource

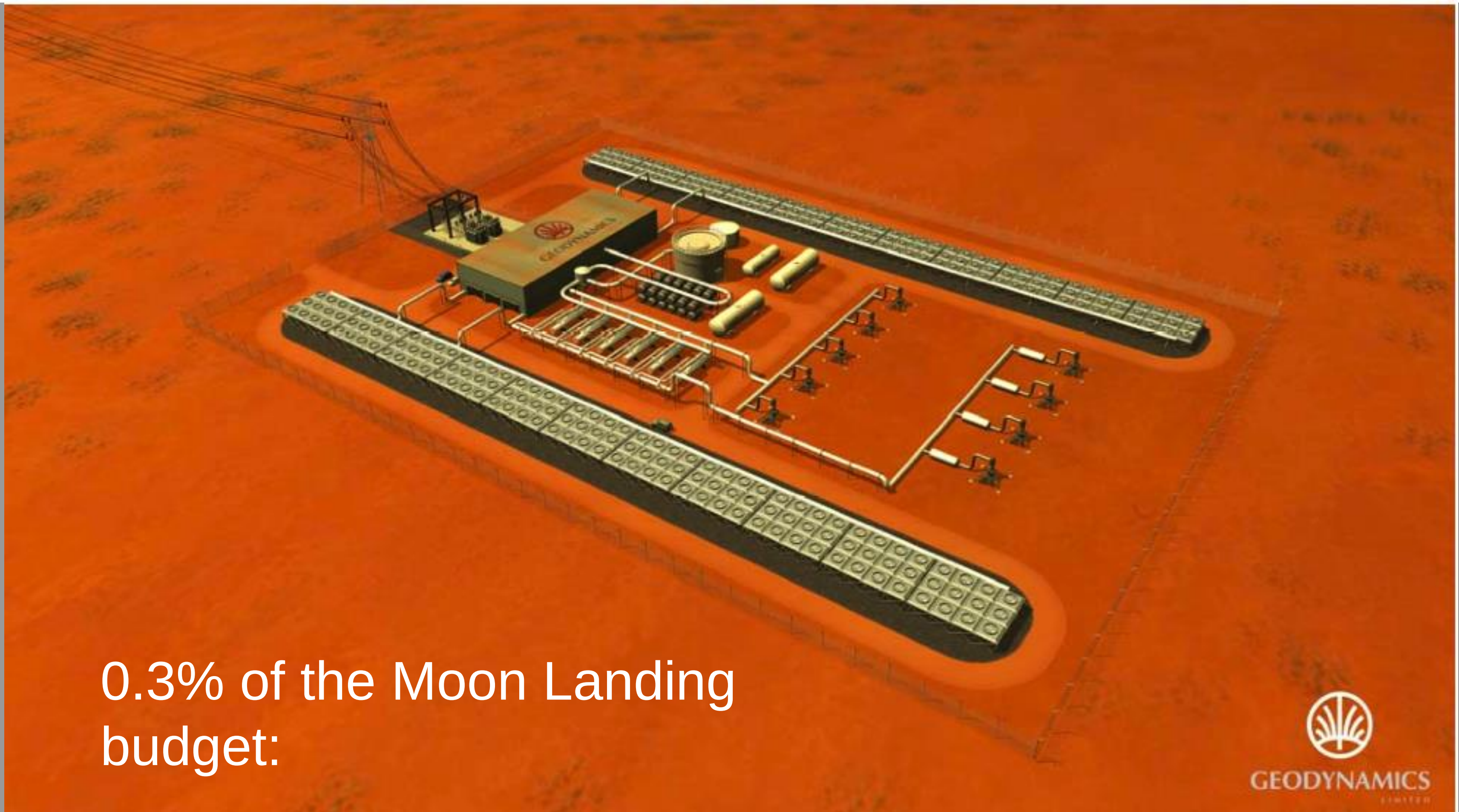
3700 m deep well in Kakkonda: close to 600° C





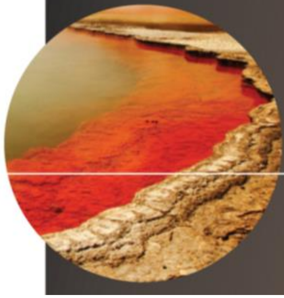
No.	Date	Standing time	Tool
①	7/18/1995	6h35	PTS
②	7/18/1995	11h45	PTS
③	7/19/1995	28h45	PTS
④	7/19/1995	33h30	PTS
⑤	7/20/1995	52h45	PTS
⑥	7/21/1995	82h20	KUSTER
⑦	7/22/1995	107h	KUSTER
⑧	7/23/1995	129h	Tablet*
⑨	7/24/1995	159h	Tablet*
⑩	9/ 2/1996	1year	Pt gauge
⑪	9/ 3/1996	1year	KUSTER

The Australian EGS Geothermal Project
Conventional Stimulation of hot granites



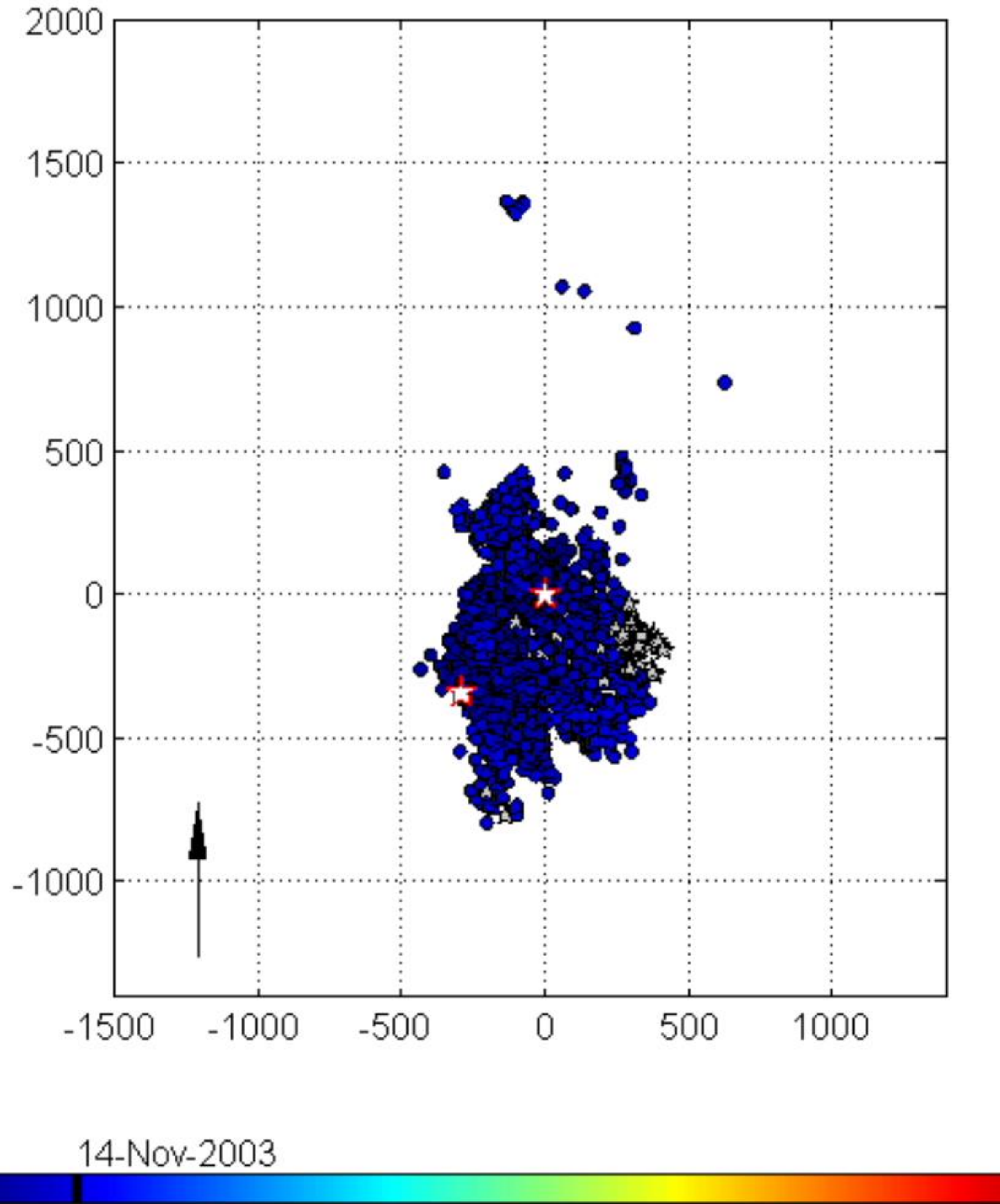
0.3% of the Moon Landing budget:

E



14-Nov 2003

First stimulation

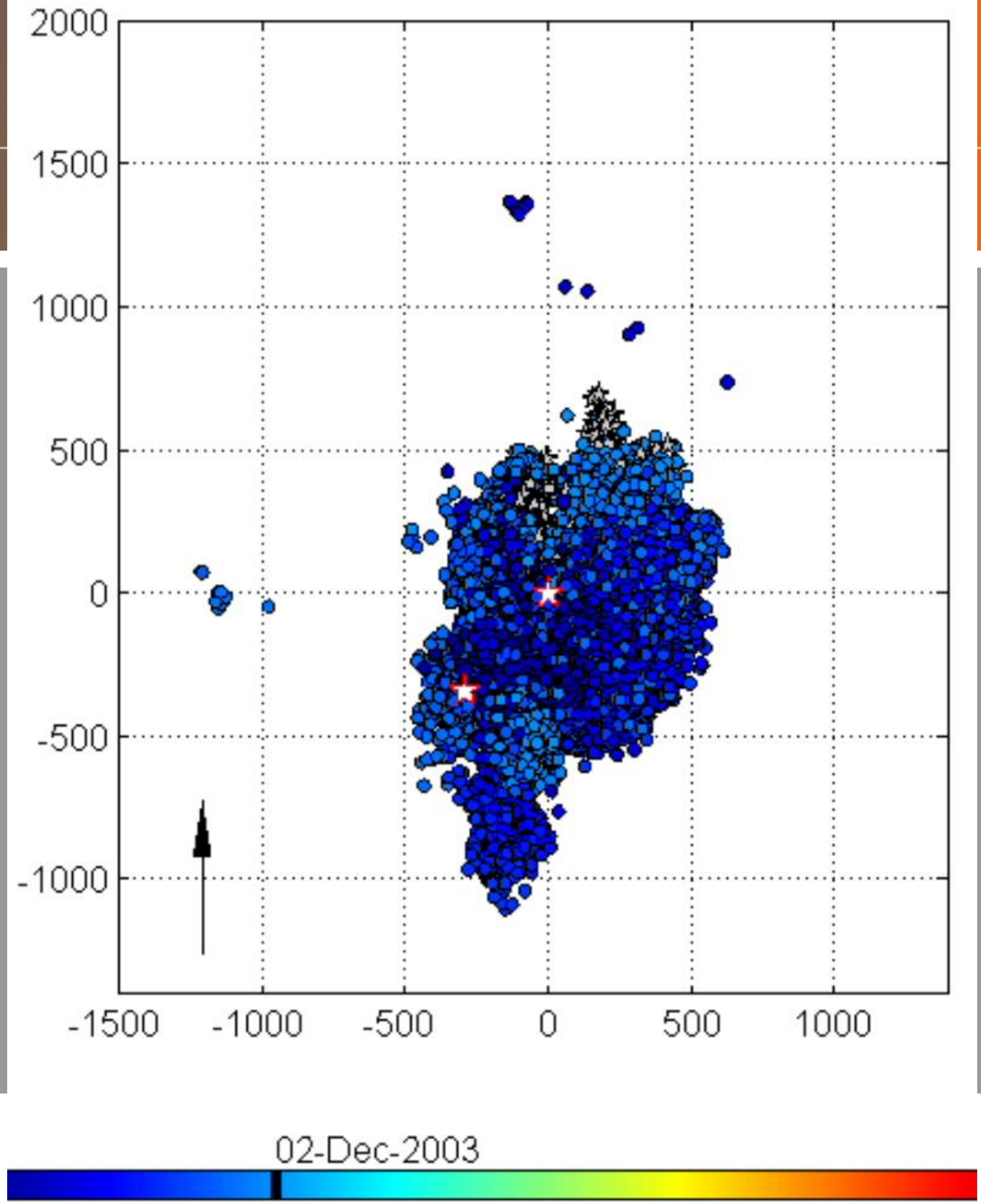


From Doone Wyborn

2-Dec 2003

Early "Off-reservoir" events to west

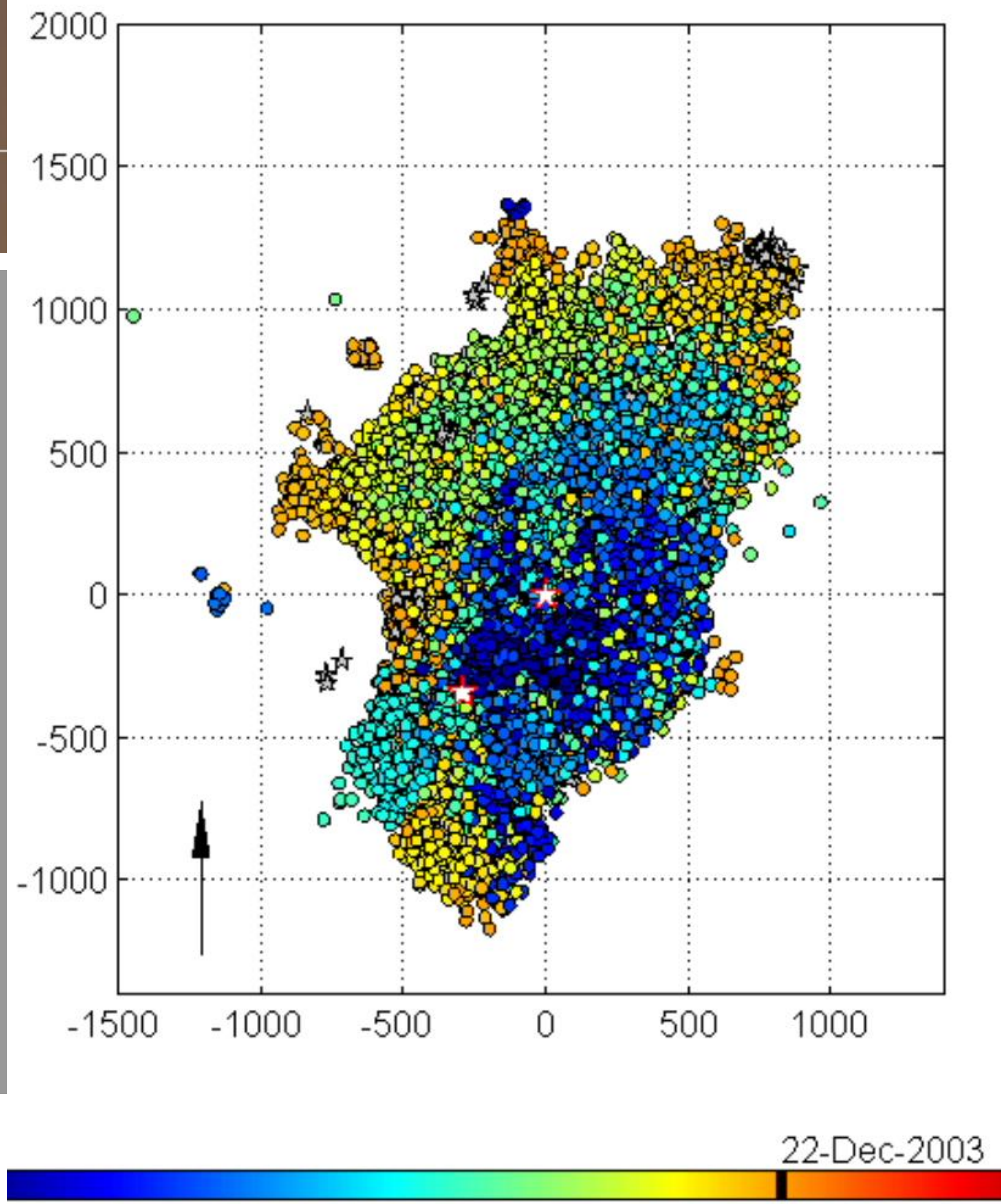
From Doone Wyborn



22-Dec 2003

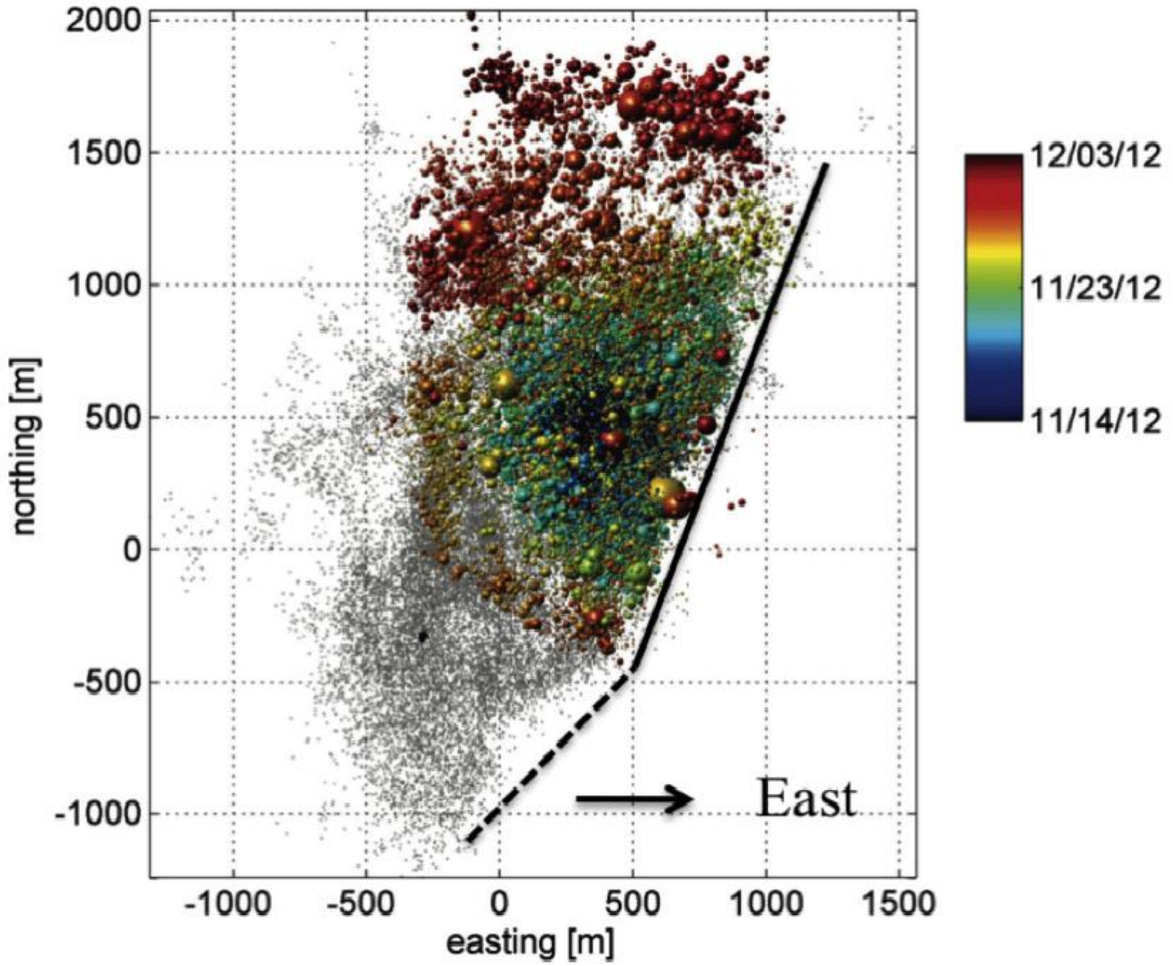
Reservoir grows to early events – connection must have already been in place

From Doone Wyborn



Habanero Stimulations 2012

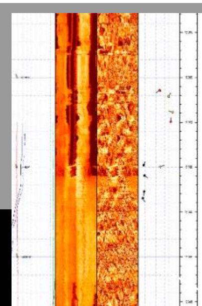
- Stimulation only possible on pre-existing geological structures
- Cut off to the east means no Stimulation shallower than 230° C
- Seismicity following the stimulation propagates well into the ductile realm down to 7 km depth



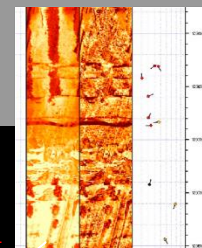
images courtesy of Geodynamics Ltd

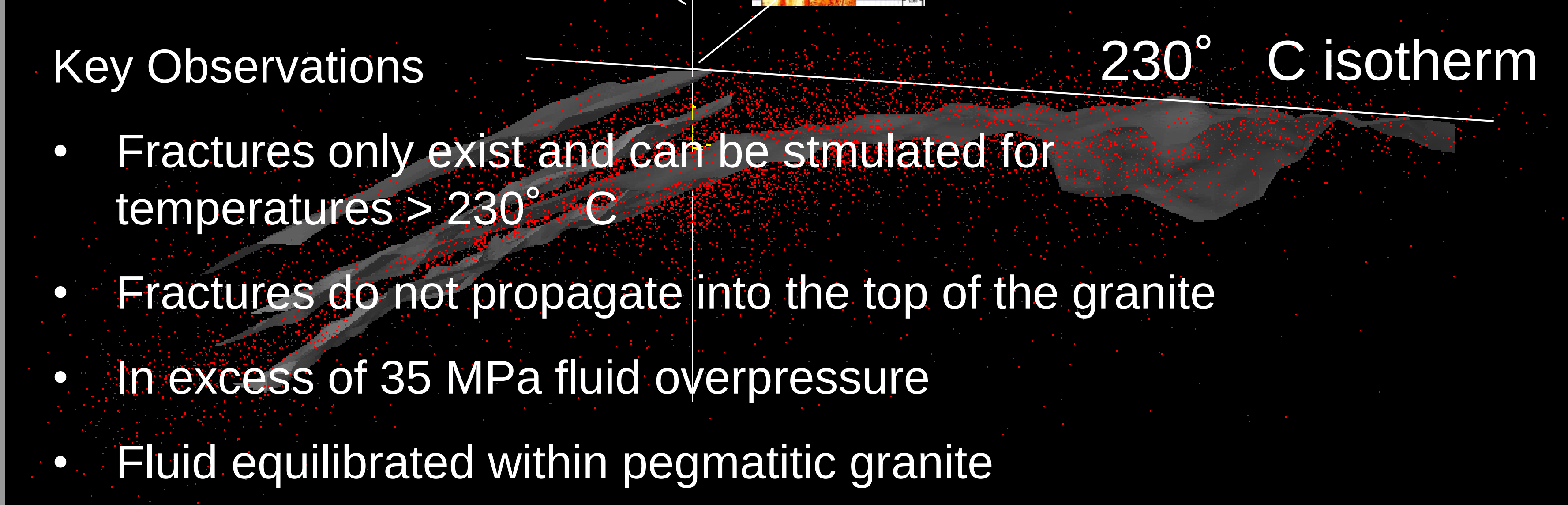
Summary of Observations Reactivation of a deep geological Fault Zone

No fracture at top of granite



First fracture at 4134m



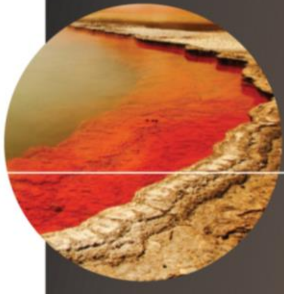


230° C isotherm

Key Observations

- Fractures only exist and can be stmulated for temperatures > 230° C
- Fractures do not propagate into the top of the granite
- In excess of 35 MPa fluid overpressure
- Fluid equilibrated within pegmatitic granite

images courtesy of Geodynamics Ltd



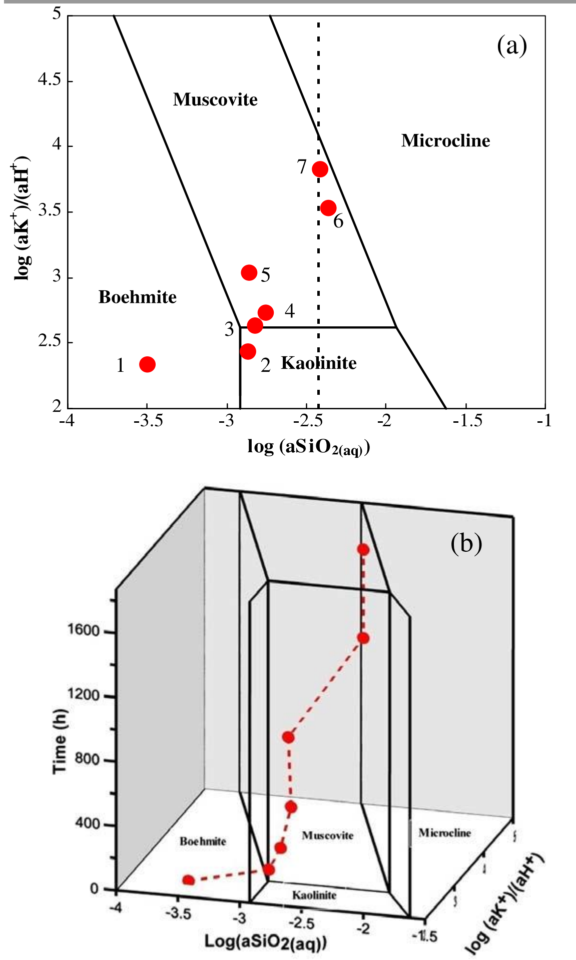
Empirical laws are not suitable for Hi-T, Hi-P Unconventional Resources

David L. Kohlstedt and Benjamin K. Holtzman 2009

"Due to constraints on the lifetime of an experimentalist, laboratory deformation experiments must be carried out at strain rates that are fast compared to those appropriate for flow processes …………the extrapolation of the understanding gained from experiments requires models to explore the interactions of driving forces and open system behavior that cannot be studied in experiment, at appropriate length and time scales and boundary conditions."

It follows that unconventional materials at extreme temperature, pressure, time and length scale require an understanding of coupling of Instabilities Across Scales

Dissolution-precipitation creep occurs when hydrous minerals dewater and long time scale tectonic drivers are available



- 3 months experiments
- activity–activity diagrams showing the phase relations in the system K2O–(Al2O3)–SiO2–H2O–HCl at 200° C and 300 bars
- Are these dewatering reactions defining a fundamental clock?

Chen Zhu, Peng Lu 2009

Need for fundamental understanding of instabilities by these fluid release reaction

IODP
Role of clay?

The deep-sea drilling vessel *Chikyu* investigated the nature of the seismic fault that shook Japan in 2011 (magnitude-9 Tohoku-Oki earthquake of 11 March 2011, record-breaking 50 metres of sideways land slip)

- **I**ntern. **O**cean **D**iscovery **P**rogram
- Japan Trench Fast Drilling Project

Nature news, Dec 2013:

- “The localization of deformation onto a limited thickness (less than 5 meters) of pelagic clay is the defining characteristic of the shallow earthquake fault” (Chester et al / Science 2013). **“That’s just weird”** says Emily Brodsky (UC Santa Cruz)
- “Lab tests confirmed that this wet clay layer is extremely slippery, and gets even more so under stress” (Ujiie et al / Science 2013)
- “The resulting apparent friction coefficient of 0.08 is considerably smaller than static values for most rocks” (Fulton et al /Science 2013)
- Fault still up to 0.31 ° C warmer than its surroundings more than a year after the quake (Fulton et al /Science 2013)

Self healing of brittle fractures
X-Ray CT in Boom Clay , a clay clock

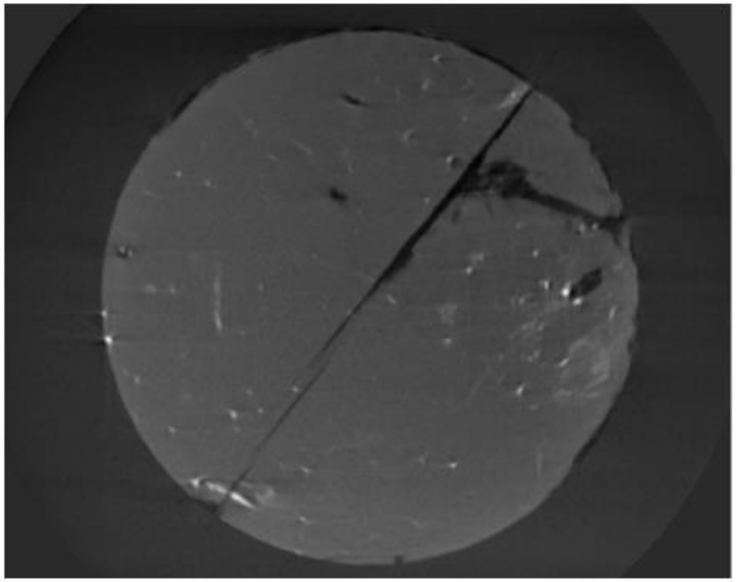


Figure 1a: Initial fracture within the sample

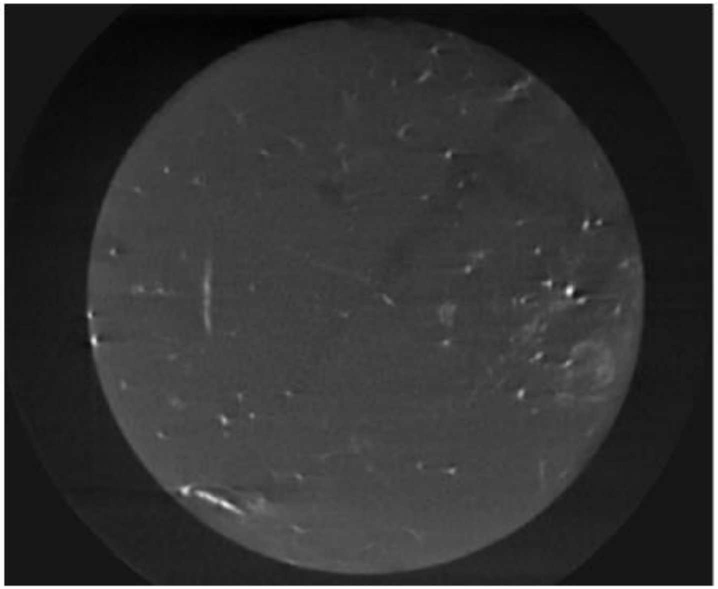
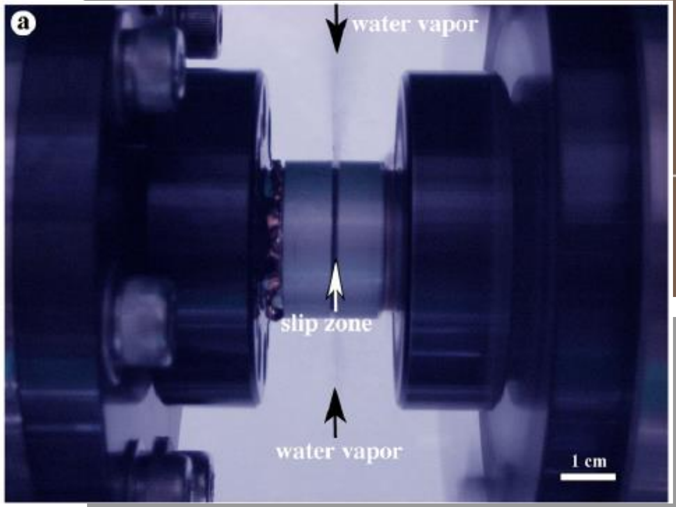
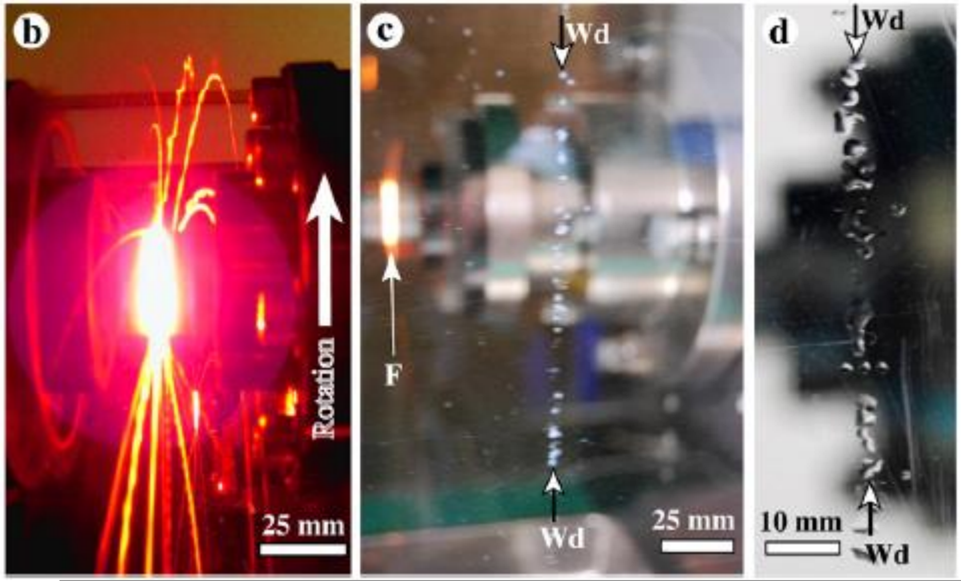


Figure 1b: Sealing after saturation o f the fracture

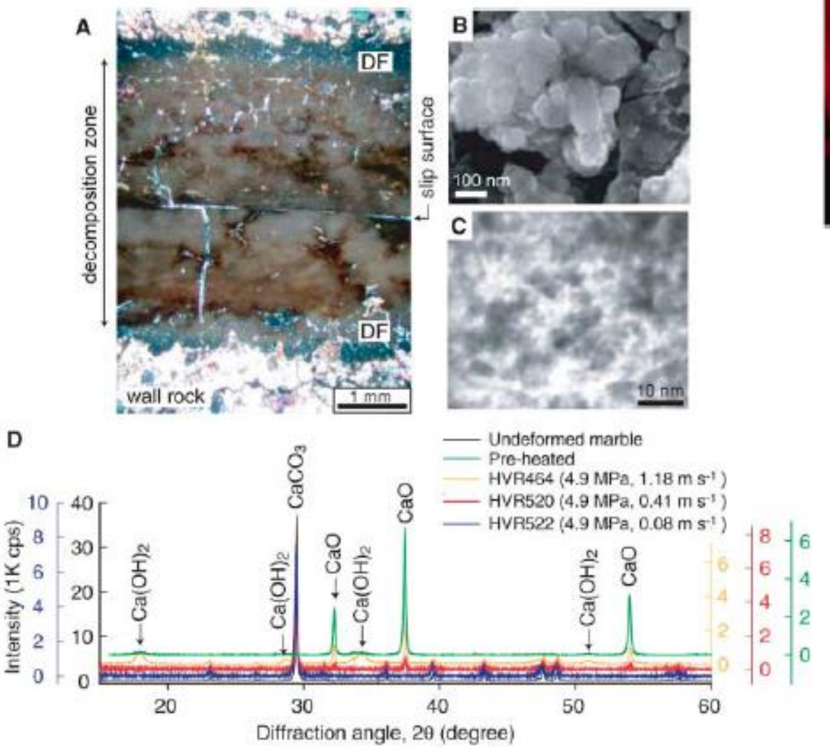
Bernier& Bastiaens 2004 Selfrac Project

$CaCO_3$ Laboratory experiments





Han et al 2007 – Science



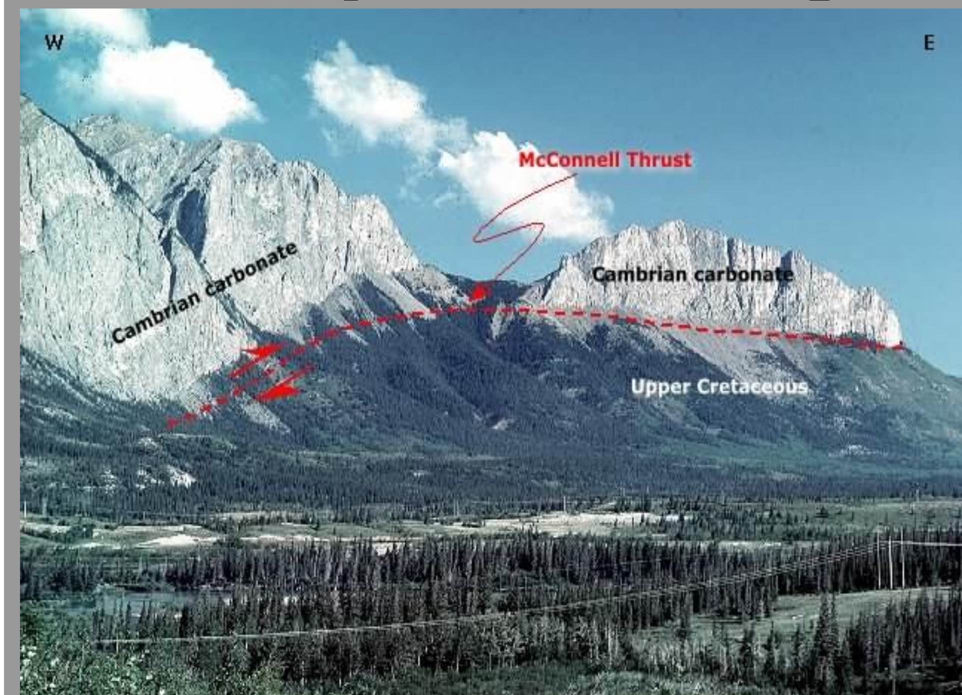
… Carrara marble at slip rates up to 1.3 meters per second demonstrate that thermal decomposition of calcite due to frictional heating induces pronounced fault weakening with steady-state friction coefficients as low as 0.06

$$CaCO_3 \rightleftharpoons CaO + CO_2$$

$CaCO_3$ McConnell thrust, Alberta

Kennedy and Logan
Journal of Structural Geology
(1997)

$$CaCO_3 \rightleftharpoons CaO + CO_2$$

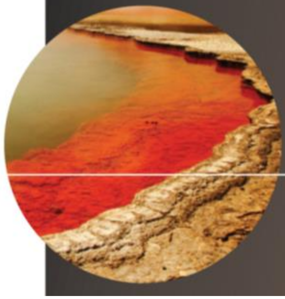


- *"importance of vein formation and calcite dissolution in the evolution of the McConnell thrust limestone mylonites."*
- *"The mylonite contains numerous, discontinuous, bedding-parallel calcite veins that range from relatively undeformed to highly sheared."*
- *"These clay seams may have contributed to the build up of high pore fluid pressures which, if intermittently reaching lithostatic conditions during displacement, would result in transient brittle failure and thrust-surface-parallel vein emplacement in an otherwise ductilely deforming rock."*
- *"Continual emplacement of veins throughout deformation ensured cycling and competition between dislocation creep and solution transfer."*

$CaCO_3$ Naukluft, Namibia

Rowe et al. / Earth and Planetary Science Letters (2012)

$$CaCO_3 \rightleftharpoons CaO + CO_2$$



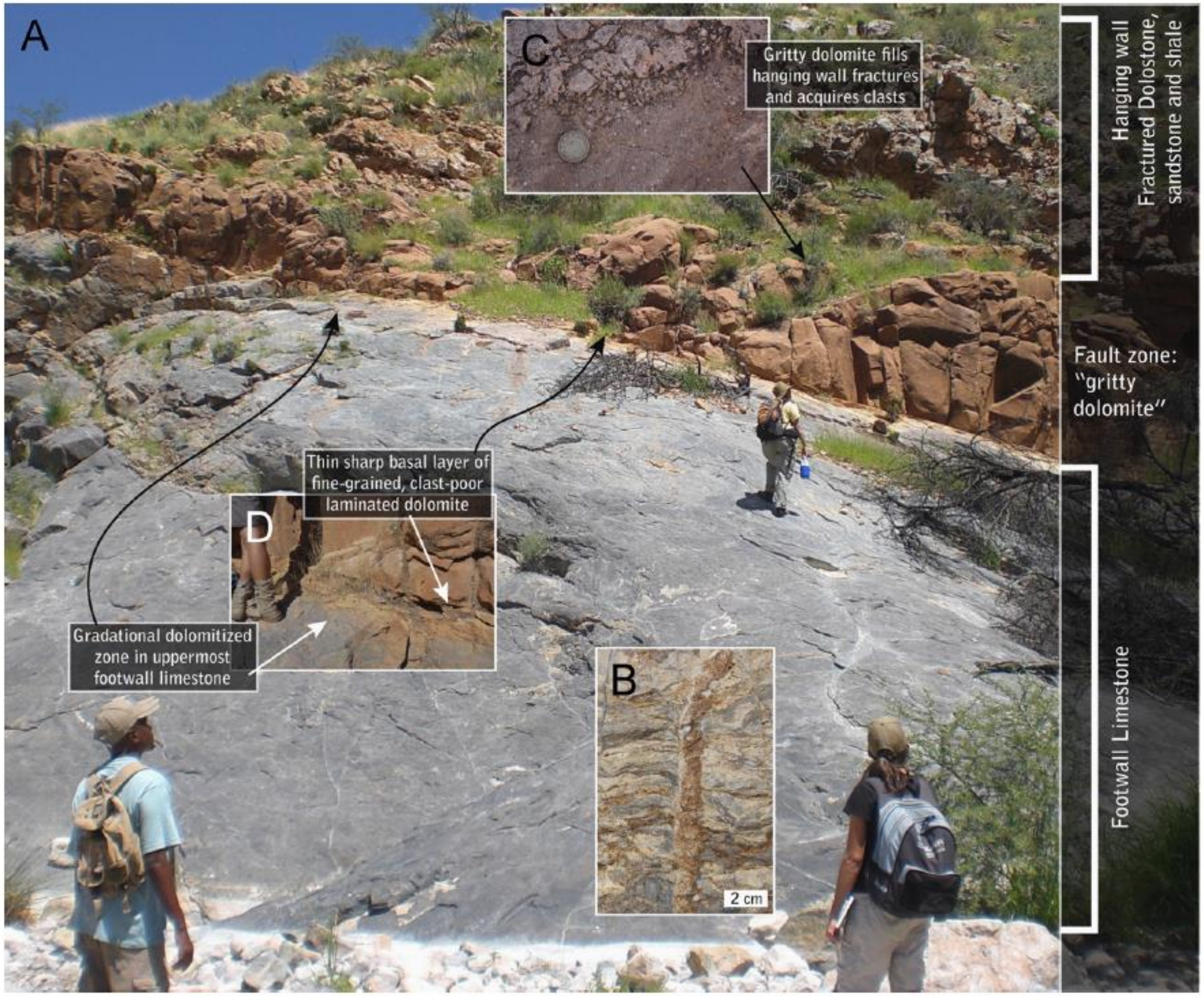


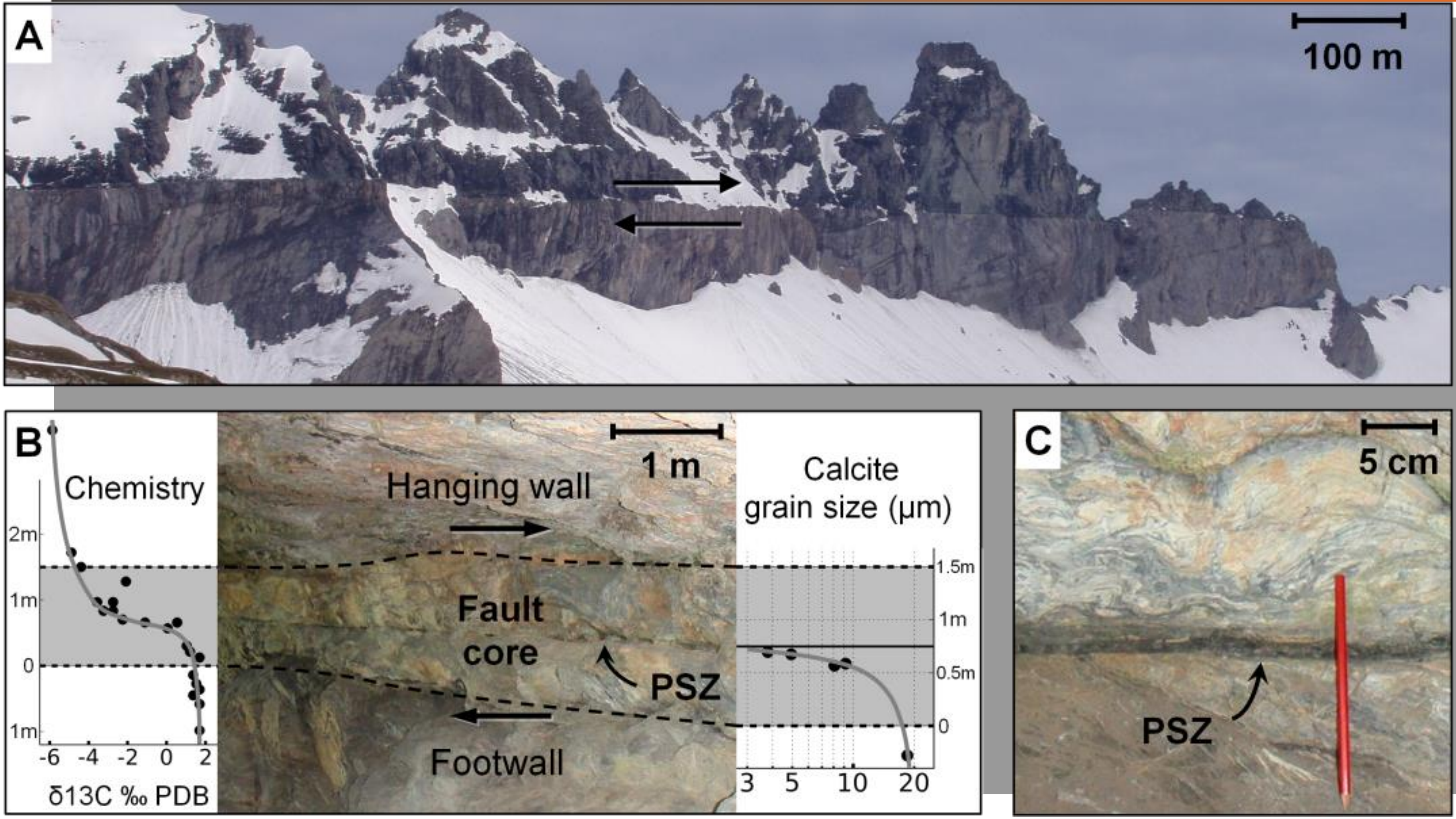
Fig. 2. (A) Outcrop of the Naukluft Thrust "Type Locality" in the Naukluft River (location shown in Fig. 1C). (B) Example of gritty dolomite injection into fracture cutting footwall partially dolomitized mylonite (photo from ~500 m east of outcrop shown in A). (C) Gritty dolomite is ~1.5–2.5 m thick at this site. Granular flow has

- Carbonate dissociation during earthquakes on Naukluft Thrust
- ~0.5 – 5m of gritty dolomite
- 2 – 3cm thick laminated

"fast frictional heating during earthquake slip provides all the necessary mechanisms to explain each textural and mineralogical element of the gritty dolomite we have described."

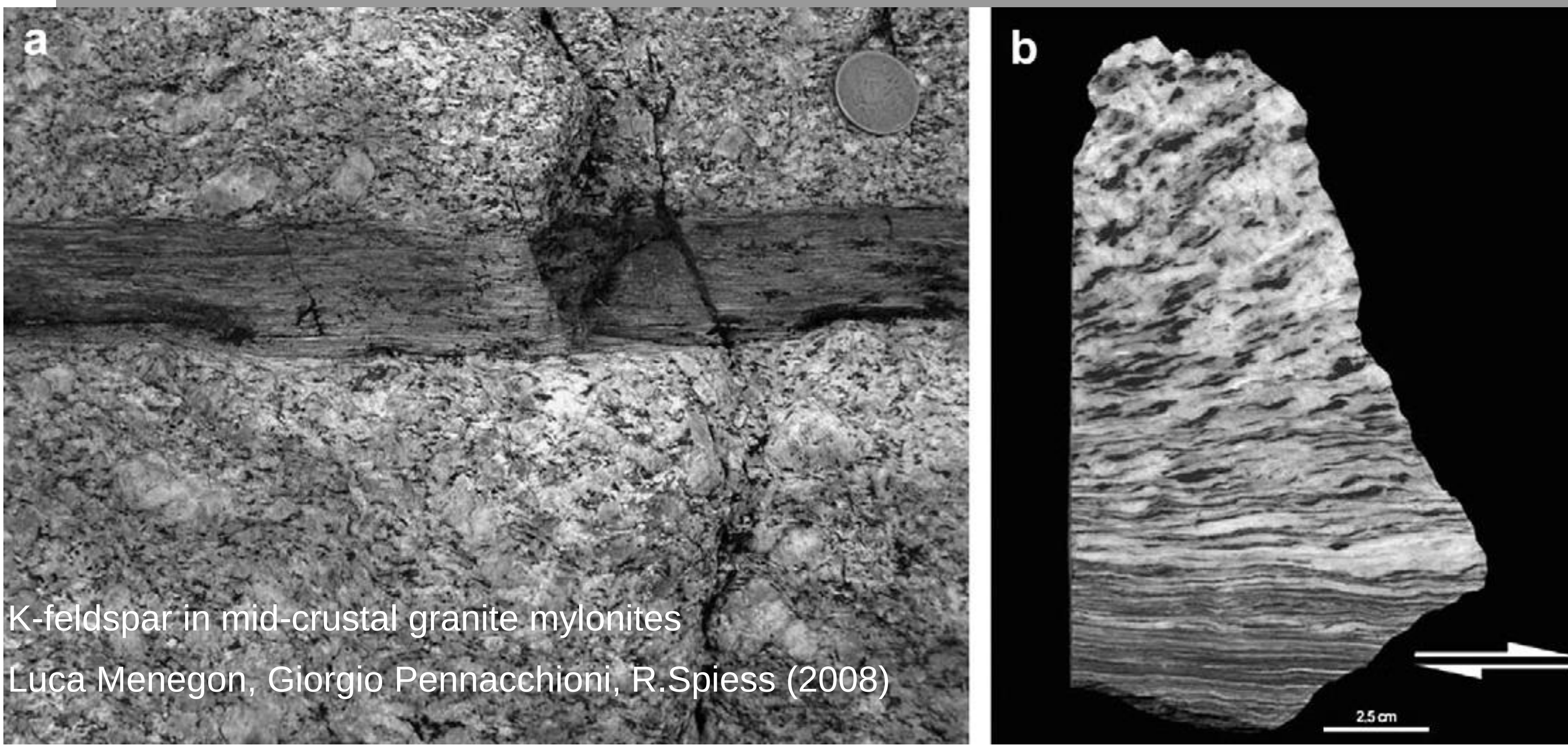
$CaCO_3$ Glarus Thrust

$$CaCO_3 \rightleftharpoons CaO + CO_2$$



K-feldspar plus H^+ dissolves in muscovite plus K^+ and quartz in aqueous solution

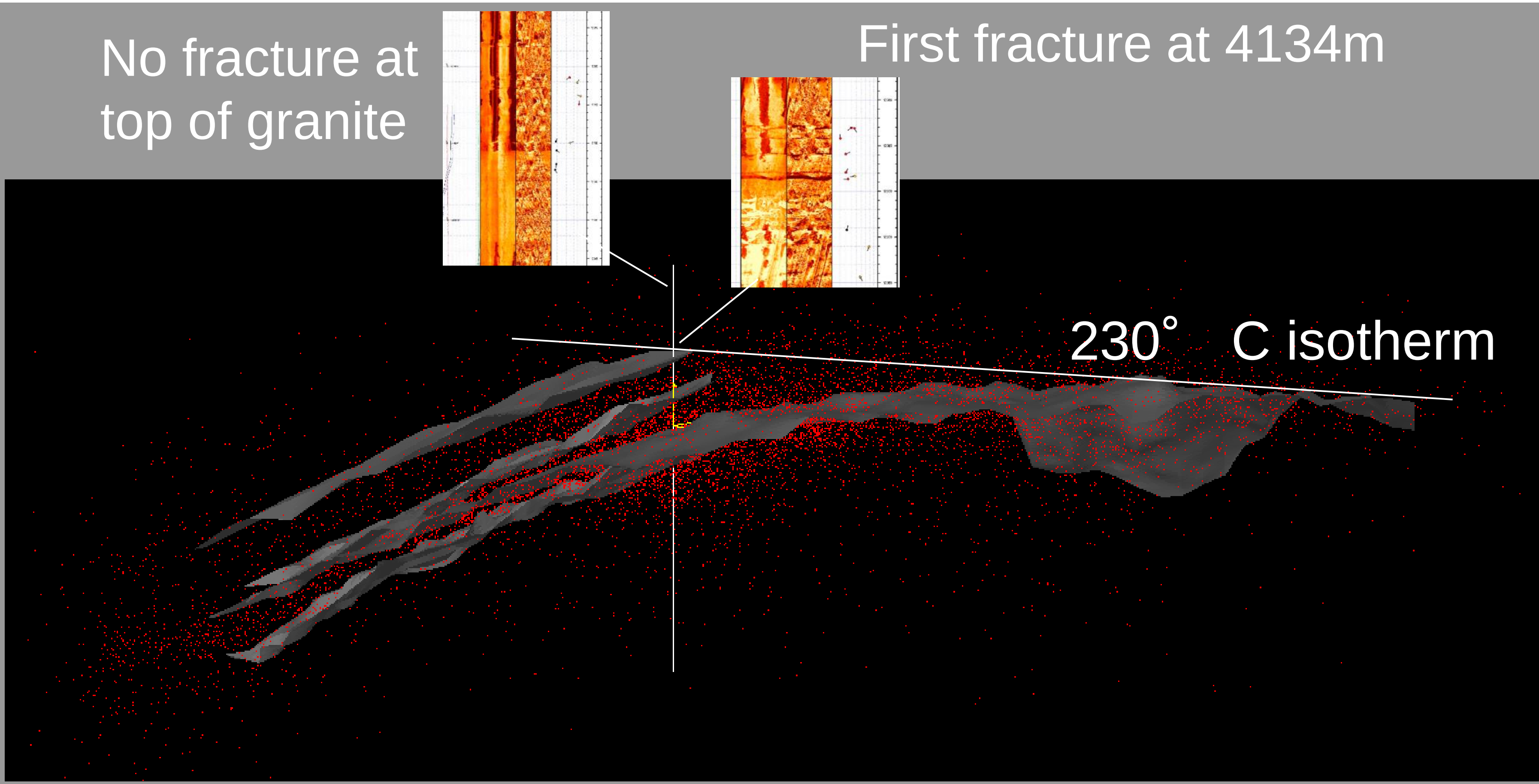
$3KAlSi_3O_8 + 2H^+ \rightleftharpoons KAl_3Si_3O_{10}(OH)_2 + 2K^+ + 6SiO_2$ (aq)



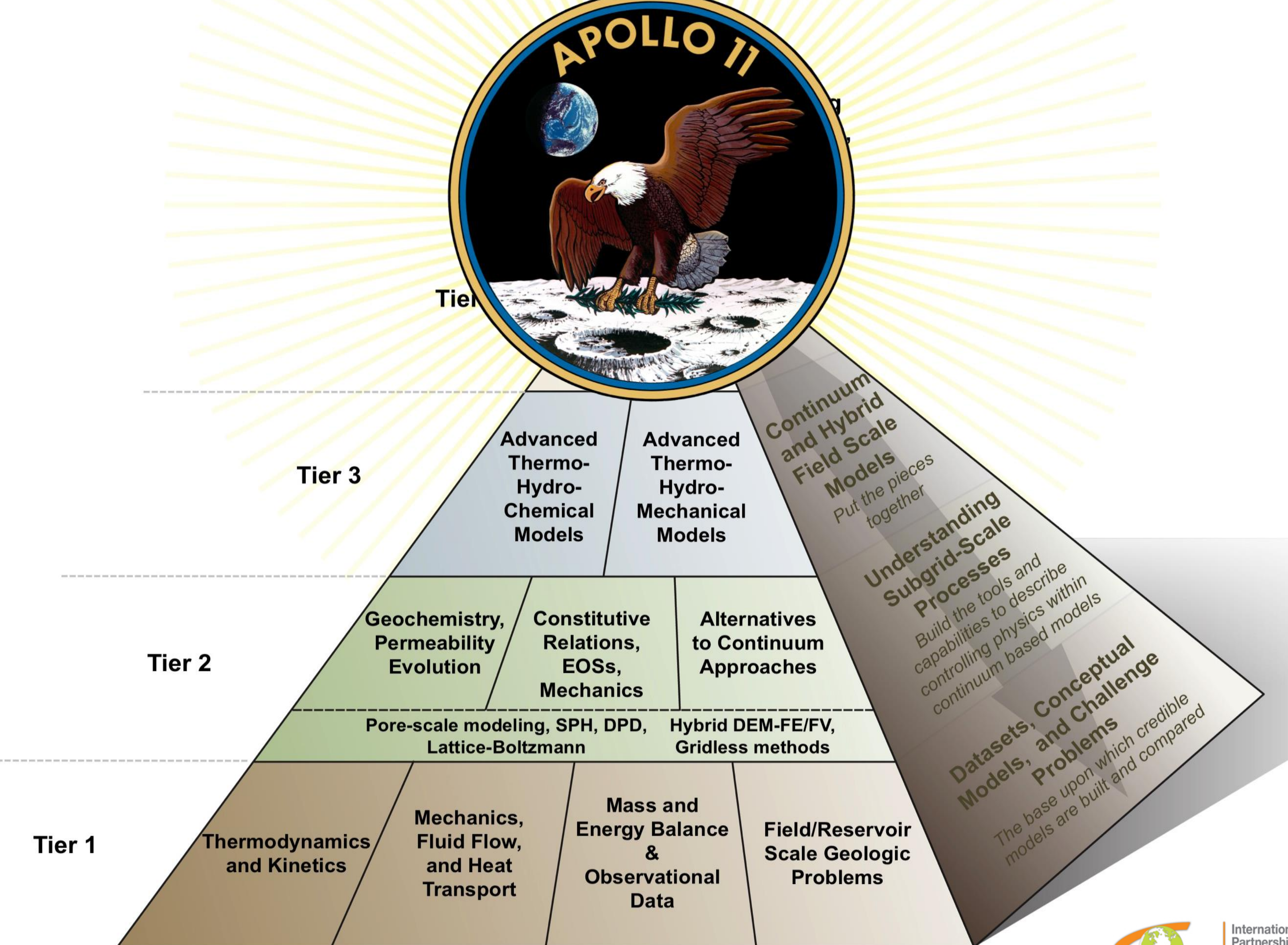
K-feldspar in mid-crustal granite mylonites

Luca Menegon, Giorgio Pennacchioni, R.Spiess (2008)

Are the 230° C cut off and the high fluid pressures sign of an activation process of Feldspar dissolution-precipitation creep?



images courtesy of Geodynamics Ltd



International Partnership for Geothermal Technology

Our Downunder contribution

The Unconventional Geomechanics Group UGG

Is not to be confused with a similarly named Ozzie shoe ware

ORIGIN 1960s (as *Ugh boot*): perhaps named after Ugh, a series of cartoon characters, or an abbreviation of **ugly**